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Sylvain Pioch
Egis Eau Co. (CDC Group)

Philippe Saussola
GESTER Geography

Kirk Kilfoyle
Nova Southeastern University, kilfoyle@nova.edu

Richard E. Spieler
Nova Southeastern University, spielerr@nova.edu

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Ecological engineering: from concepts to applications

Ecological design of marine construction for socio-economic benefits: ecosystem integration of a pipeline in coral reef area

Sylvain Pioch[a,b,] *, Philippe Saussola, Kirk Kilfoyleb[c], and Richard Spieler[b, c]

[a]*Egis Eau Co. (CDC group), Marine Biodiversity, Environmental Engineering, 78 allée Jhon Nappier, 34000 MONTPELLIER, France*
[b]*Oceanographic Center and 3National Coral Reef Institute, Nova Southeastern University, 8000 N Ocean Drive, Dania, Florida, USA 33004*
[c]*GESTER Geography, rue de l'abbé de l'épée, Université Montpellier 3, 34000, MONTPELLIER, France*

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Abstract

It is critical to understand that an ecosystem integration of construction requires a close Engineering/Biology partnership to meet socio-economic benefits in management goals. Biologists are not typically trained or licensed for the requisite engineering involved in construction. Likewise, non-biologists designing habitat often can lead to egregious results. For example, unintentionally constructing the wrong habitat, i.e., refuge for predators in a nursery area, or habitat that facilitates the spread of non-desirable species can increase, rather than ameliorate, the impact of construction.
In recent years, Pioch and co-workers (unpublished) developed an alternative to the "classic" engineering approach to marine construction. This new approach, of construction "integrated in ecosystem", is now operational or in the planning stage for marinas, harbours, seawalls, dykes and pipelines. We will present the example of Mayotte project (France, West Indian Ocean) in 2008 established a 2,600 m underwater pipe line for around US \$8.8 million (6.8 M€), linking "Grande Terre" to "Petite Terre" island, in a coral lagoon (marine protected area).

Keywords : coast; ecosystem services; mitigation; artificial habitat; ecological engineering; restoration; marine biodiversity.

1. Introduction

The alarming global loss of marine biodiversity is the result of pollution, global warming, overfishing, and especially destruction of habitats in coastal area [1]. Recently, these observations required governments and developers to consider the marine environment footprint of all marine projects [2]. Moreover, habitat design by non-biologists can lead to inadequate results, such as spread facilitation of non-desirable species [3,4]. Aware of these From this awareness, we developed an ecosystemic approach of marine construction projects.

Usually, impact studies try, when it is not possible to totally avoid negative impacts, to mitigate environmental damage of a "technical" project that is aimed at socio-economical benefits. We worked on the ecosystem integration of a pipeline project in Mayotte island (French Department, West Indian Ocean), by elaborating an effective design

* Corresponding author.
E-mail address: sylvain.pioch@egis.fr.

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that would create artificial habitat for fauna and flora. The project became "pro-active" for the environment, with socio-economical and ecological benefits as final aims.

We developed two aspects:

- A methodological approach of project environmental characteristics database (as well as bio-physical and socio-economical parameters),
- The conception of the pipeline itself as an artificial habitat specifically designed for local fauna and flora.

In our paper, we will explain, given the local biodiversity, why we proposed the use of specific ballasting blocks called "eco-weights", which not only can ensure the stability of the pipe during cyclonic conditions (great waves and currents) but can also create new artificial habitats. We will first describe the ecosystem, the social interest in maintaining a healthy ecosystem, and then the methodology to create an eco-engineered construction.

2. Example of ecosystem integration of marine construction: pipe-line project in Mayotte

The Mayotte lagoon encompasses approximately 1,500 km², including 200 km of barrier reef and one of the largest closed lagoons in the world [5]. A biological inventory of the area recorded 239 fish species, 400 shellfish species, and more than 270 seaweeds [6]. The internal reef is a nursery area with a high concentration of juvenile fishes. Since the 1960s the local population has risen from 25,000 to 200,000 people. The high anthropogenic pressure created by this population has resulted, in part, in ecosystem damage through overfishing, pollution, and sedimentation (erosion due to construction of houses). Moreover, natural events (i.e., hurricanes) have impacted the area. Together, the anthropogenic and natural impacts have resulted in a destruction of 40% of the coral reef habitats [7]. The main consequence of this habitat loss is a decrease in refuges for juvenile fish and a diminution of biodiversity. From a social point of view, the lagoon is an important source of proteins for local citizens. Traditional fisheries constituted the second largest economic activity in the region in 2000, supporting 3,600 boating fishermen [8].

The environmental agency (DIREN) asked to the pipeline construction applicant, SIEAM (a public company), to discuss the ecosystem risks and to provide a construction solution to minimize impact on environment as part of their bid. The impact study resulted in 3 suggestions to avoid or reduce damage: choosing a minimum-damage pipeline track relative to coral stands (even if this kind of work is usually difficult to realize), ecological assessment, and a quick completion of construction (less than 8 months). However, it did not address the loss of habitat due to construction. The ecosystemic approach was chosen as an exclusive and original solution. Specifically, actions to create (restore) habitat in the lagoon as part of the requisite pipeline construction were outlined. It was proposed to use "eco" weights in order to stabilize the pipeline on the seabed, as well as to create and restore habitat and biodiversity in the lagoon. It is particularly noteworthy that, by incorporating "ecological" techniques, the total construction cost was increased by less than 1%.

The project area started at the beach of Mamoudzou city on Grande Terre and ran across the lagoon to Dzaoudzi city on the island of Petite Terre, with a maximum depth in the lagoon around 26 m. An identification of the coral formations along the layout of the pipe was undertaken by Bigot [9]. An ecological survey was done on the track of the pipeline using the methods of English [10] and Conand [11]. The survey identified: community structure (by families and species), biotopes (geo-morphological), habitats, and fishes relationships using the classification of Nakamura [12], i.e., A= benthic, B = demersal, and C = pelagic fish species as juveniles or adults [9].

Four biotopes were found and mapped in which 8 communities existed with both A and B species. Juveniles of these species were found in shallow water and adults in deep water. This survey was used to define the ecological sensitivity (ES) of specific areas based on the associated communities and biotopes. Three levels of sensitivity were determined (low, medium, or high) by examination of 1) species richness of communities (family level), 2) taxonomic diversity (family level), 3) kind of substratum: mud, sand, rock, or coral, 4) endangered or threatened species (species level), 5) function of habitat: nursery (juveniles), spawning, breeding (adults), or feeding (juveniles or adults).

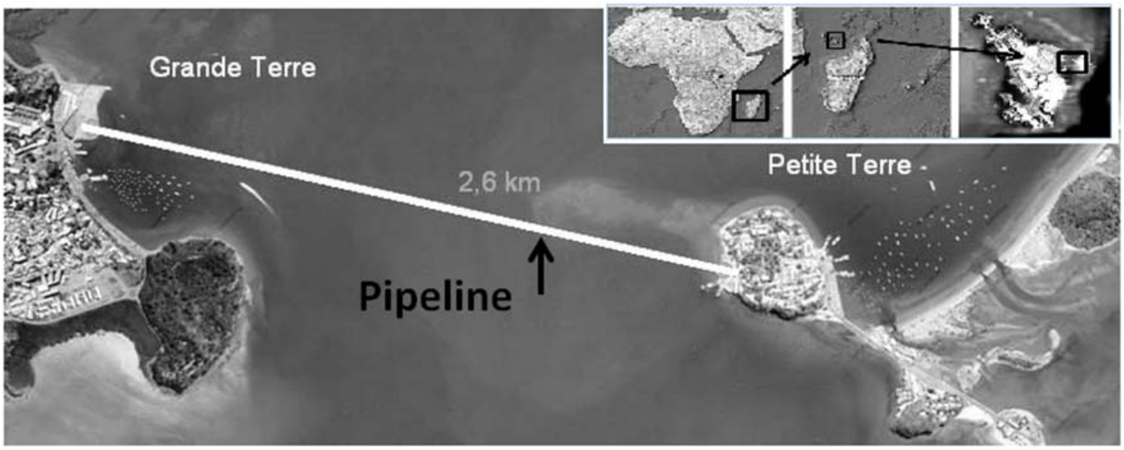

Figure 1 : Map of the project between Mamoudzou and Dzaoudzi.

The ecological vulnerability (EV) included also stakeholder usage (Utilization Factors, UF) and Environmental Risks (ER). For this study ER was defined by coastal construction both emerged (breakwater, dike, pontoon, boat-ramp) and submerged (pipeline, energy cable, phone cable), as well as boat navigation and current (direction and speed). Thus EV was determined with the formula: EV = ES + (UF and ER). The vulnerability was categorized as positive (high vulnerability) or negative. These factors were then used to define the environmental priorities and the construction design for different areas (Table 1). Two main habitat and species relationships were defined: 1) shallow water, juveniles from benthic and demersal species with low sensitivity and vulnerability to construction impact and 2) deep water, adults, from mainly benthic and also demersal species with medium and high sensitivity and vulnerability.

Table 1: Sites, associated ecological parameters and the module type used for weighting the pipeline.

Biotopes	Communities	Fish Type	Juvenile or Adult	Ecological Sensitivity	Ecological Vulnerability	Model Type
N°1 Shallow water by beaches	1	A, B	J	low		Rock
	8	A, B	J	low	-	
N°2 Sand with scattered coral	2	A, B	A	medium	+	Tile with rugosity
	3	A, B	A	high	+	
	4	A, B	A	low	-	Tile
N°3 Muddy-sandy channel	5	B	A	medium	+	Tile with rugosity
	6	B	A	low	-	Tile
N°4 Muddy with sand + coral	7	A, B	A	medium	+	Tile with rugosity

The engineering part of the project consisted primarily in conducting physico-oceanic surveys to design the pipeline. The main parameters were 1) morpho-bathymetric features, 2) climatic events in the lagoon: maximum waves and surfaces / bottom currents for a once-in-500 year occurrence (hurricanes), and 3) sediment type (sand, bottom, rocks) and coverage.

Affixing the pipeline to the substrate was required to minimize damage to the pipe and surrounding habitat due to movement. Typically, this has been done with sand anchors and weights that are concrete squares or rings (ring weights are needed to minimize the effect of scouring). For the project, the pipeline PEHD PN16 (diameter is 400 mm) was chosen. It required an anchor in the sediment every 10 meters, with a total of 206 concrete weights of between 1 and 3 tons each.

It was hypothesized that these weights, which have a strong impact on seabed because of their volume and shape, could be used to create an artificial habitat that would enhance biodiversity: eco weights. Technical feasibility had to be considered: their weight needed to be 1-3 tons, a linkage system with sand anchors was required, as was a ring design, serial fabrication, and easy transportation. Further, they needed to be manufactured and deployed with the usual tools for this kind of work. Cost was also a major consideration. Out of 5 designs initially tested, only 2 of them were acceptable due to technical, economic, and ecological concerns.

The first module, called Rock, was designed to create effective habitat for juvenile fishes of species A. This design mimicked shallow biotopes of area 1 containing communities 1 and 8. It consisted of 2 half-rings joined like a sandwich on the pipe. They are separated by 4 pods, 2 for each side of the pipe, creating space between each part. Porous rocks (local basaltic rocks) were inserted on top to add species-specific structural design/refuge. All shelters were appropriately sized to be suitable for benthic and demersal juveniles based on past AH research. The insertion of natural rocks and the soft curve of the shape (half-ring) will add to the future integration with the natural seascape.

The second module, called Tile, was designed to create effective habitat for adult fishes of species A and B. It was designed to mimic deeper biotopes of areas 2, 3, and 4, with added treatment to accentuate the rugosity for sensitive communities 2, 3, 5, and 7. No treatment was made for the non-sensitive communities 4 and 6. The rugose surface was incorporated to enhance corals, as well as other invertebrate larvae and algal settlement. It has the same shape as the Rock model, but the space between the half-ring is an important difference. All the shelters are shelter-scaled and provide refuge suitable for benthic species on the upper surface of the weight with a tile-like system (4 half-tunnels), and demersal species between the half-rings. Rugosity was accentuated to accelerate colonization of faunal assemblages. The shape (half-ring) and the tile-linked half-tunnel are all non-angular soft shapes, which also should enhance future seascape integration.

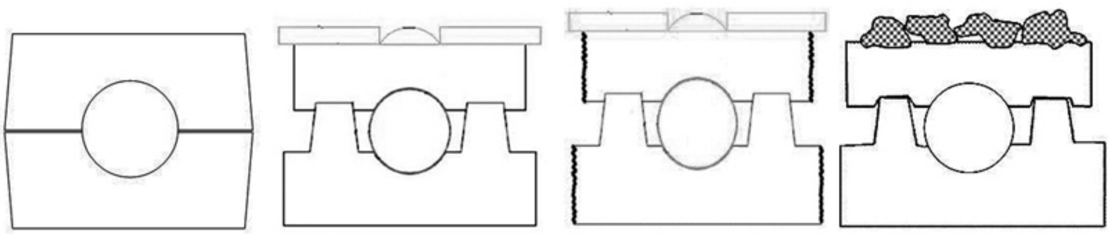

Figure 2. Depiction of a vertical face of the pipeline weights described in the text. A = normal weight, B-D = “eco” weights. B = Tile, C= Tile + rugosity, D = Rock. The center circle represents the pipeline.

3. Results

Efforts to install the pipe began in mid-December 2009 and were finalized in March 2010. The original timeline of five months had been calculated on the basis of previous pipeline construction projects. This timeline was met; thus, it took no longer to construct and deploy the pipeline. There were also no work interruptions or other problems related to the eco-weight modules. An ecological assessment began in March 2010 and the first video survey was done one month later [13]. Juveniles were noted in the first assessment under the Rock models for A and B commercial species (*Panulirus versicolor* and *Epinephelus flavocaeruleus*). Several different adult species were present around the Tile models, both under the tile-like habitats and between the half-rings. On the video, a first semi-qualitative assessment showed families belonging to Pomacentridae, Labridae, Chaetodontidae, Holocentridae and Acanthuridae (other species identified on the video: *Pterois volitans*, *Cheilodipterus quinquelineatus*, *Neopomacentrus cyanomos*, *Pomacentrus pavo*, *Amblyglyphidodon leucogaster*, *Pomacentrus caeruleus*, *Anthiinae* spp., and *Pseudochromis* spp.). Invertebrates (e.g. colonial hydroids) were also seen on the rugose models. Fish abundance on the old pipeline, still in use and located 5 m away from the new construction, was insignificant. In contrast, schools of >15 fishes from 3 to 5 different families were seen on the new pipeline (L. Bigot, personal communication). Monitoring of the biota on the new construction will continue for 3 years. The first video was shown to the stakeholders (artisanal fishermen, scuba divers) and policy makers. They were pleased to see that the project did return technical and ecological services with socio-economic benefits. After this first construction, the Saint Leu (Reunion Island, West Indian Ocean, France) authorities asked that the pipeline of their water treatment plant effluent be constructed with eco-weights, and work is scheduled to begin December 2010.

4. Conclusions

Integrating the ecosystem into the design of marine projects potentially impacts the socio-economical development of coastal areas through the enhancement of biodiversity. However, this approach should not be a substitute for taking into account the sustainable use of ecosystems. Clearly, future development and construction requires new concepts to support biodiversity enhancement. Nevertheless, the mitigation of ecosystem degradation remains difficult if we wish to use the environment in a sustainable manner.

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